

Duane Smith

# LANDSLIDES

## Analysis and Control

*Special Report 176*

Robert L. Schuster  
Raymond J. Krizek  
*editors*

Transportation Research Board  
Commission on Sociotechnical Systems  
National Research Council

NATIONAL ACADEMY OF SCIENCES

Washington, D.C.

1978

Transportation Research Board Special Report 176  
Edited for TRB by Mildred Clark  
Price: paper cover \$12.00; hard cover \$14.00

Additional copies of Figure 2.1 (in pocket in back of book) are available for \$2.00 each. Please send payment with order.

modes

- 1 highway transportation
- 3 rail transportation

subject area

- 63 mechanics (earth mass)

Transportation Research Board publications are available by ordering directly from the board. They may also be obtained on a regular basis through organizational or individual supporting membership in the board; members or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Notice

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The views expressed in this report are those of the authors and do not necessarily reflect the view of the committee, the Transportation Research Board, the National Academy of Sciences, or the sponsors of the project.

Library of Congress Cataloging in Publication Data

National Research Council. Transportation Research Board.  
Landslides, analysis and control.

(Special report - Transportation Research Board, National Research Council; 176)

Includes bibliographies and index.

1. Slopes (Soil mechanics) 2. Landslides. I. Schuster, Robert L. II. Krizek, Raymond J. III. Title. IV. Series: National Research Council. Transportation Research Board. Special report - Transportation Research Board, National Research Council; 176.  
TA710.N32 1978 624'.151 78-27034  
ISBN 0-309-02804-3

© 1978 by the National Academy of Sciences. All rights, including that of translation into other languages, are reserved. Photomechanical reproduction (photocopy, microcopy) of this book or parts thereof without special permission of the publisher is prohibited.

This work may be reproduced in whole or in part for official use of the U.S. government.

Sponsorship of the Papers in This Special Report

DIVISION A—REGULAR TECHNICAL ACTIVITIES

Kurt W. Bauer, *Southeastern Wisconsin Regional Planning Commission, chairman*

GROUP 2—DESIGN AND CONSTRUCTION OF TRANSPORTATION FACILITIES

Eldon J. Yoder, *Purdue University, chairman*

Task Force on Review of Special Report 29—Landslides

Robert L. Schuster, *U.S. Geological Survey, Denver, chairman*

David S. Gedney, *Federal Highway Administration*

Raymond J. Krizek, *Northwestern University*

David L. Royster, *Tennessee Department of Transportation*

Dwight A. Sangrey, *Cornell University*

William G. Weber, Jr., *Washington Department of Transportation, Yakima*

Tien H. Wu, *Ohio State University*

John W. Guinnce, *Transportation Research Board staff*

Ch  
IN

Ch  
SI

C  
R

# Contents

*Chapter 1: Robert L. Schuster*

## INTRODUCTION

- Scope of This Volume, 1
- Definitions and Restrictions, 2
- Economics of Slope Movements, 2
- Legal Aspects of Slope Movements, 6
  - Landslides and Transportation Routes, 6
  - Landslides and Property Development, 8
- Acknowledgments, 9
- References, 9

*Chapter 2: David J. Varnes*

## SLOPE MOVEMENT TYPES AND PROCESSES

- Terms Relating to Movement, 12
  - Kinds of Movement, 12
  - Sequence or Repetition of Movement, 23
  - Rate of Movement, 24
- Terms Relating to Material, 24
  - Principal Divisions, 24
  - Water Content, 24
  - Texture, Structure, and Special Properties, 24
- Terms Relating to Size or Geometry, 25
- Terms Relating to Geologic, Geomorphic, Geographic, or Climatic Setting, 25
- Terms Relating to Age or State of Activity, 26
- Forming Names, 26
- Causes of Sliding Slope Movements, 26
  - Factors That Contribute to Increased Shear Stress, 26
  - Factors That Contribute to Low or Reduced Shear Strength, 27
- References, 28
- Bibliographies, 33

*Chapter 3: Harold T. Rib and Ta Liang*

## RECOGNITION AND IDENTIFICATION

- Terrain Evaluation for Landslide Investigations, 34
  - Basic Factors, 34

- Regional Approach to Landslide Investigations, 36
- Landforms Susceptible to Landslides, 36
- Vulnerable Locations, 37
- Procedure for Preliminary Investigations of Landslides, 41

- Map Techniques for Landslide Detection, 43
  - Topographic Maps, 43
  - Geologic Maps and Reports, 44
  - Agricultural Soil Survey Reports, 47
  - Special Maps and Reports, 47
- Remote-Sensing Techniques for Landslide Detection, 48
  - Use of Aerial Photography, 48
  - Use of Other Remote-Sensing Systems, 66
- Field Reconnaissance Techniques, 69
  - Field Evidence of Movement, 71
  - Field Identification of Slope-Movement Types, 72
- Conclusions, 78
- References, 79

*Chapter 4: George F. Sowers and David L. Royster*

## FIELD INVESTIGATION

- Scope of Field Investigations, 81
  - Topography, 82
  - Geology, 82
  - Water, 83
  - Physical Properties, 83
  - Ecological Factors, 83
- Planning Investigations, 84
  - Area of Investigation, 84
  - Time Span, 84
  - Stages of Investigation, 84
- Site Topography, 85
  - Aerial Survey, 85
  - Ground Surveys, 86
  - Representation of Topographic Data, 89
  - Profiles, 90
  - Displacement Vectors and Trajectories, 90

- Subsurface Exploration, 91
  - Geologic Reconnaissance, 91
  - Boring, Sampling, and Logging, 94
  - Test Pits and Trenches, 95
  - Geophysical Studies, 95
  - Correlation Representation, 98
- Surface Water and Groundwater, 99
  - Importance of Water, 99
  - Surface Water, 100
  - Groundwater, 100
  - Groundwater Observations, 101
  - Permeability, 102
  - Springs and Seeps, 102
  - Correlation, 102
- Environmental Factors, 103
  - Weather, 103
  - Human Changes Before Construction, 103
  - Changes Brought by Construction, 104
  - Effect of Ecosystem on Sliding, 104
  - Effect of Sliding on Ecosystem, 104
- Field Testing, 105
  - Borehole Tests, 105
  - Large-Scale Pit Tests, 108
  - Borehole Dynamics, 109
  - Geophysical Tests, 109
- Correlation of Data, 110
  - Areal Variations, 110
  - Cross Sections, 110
  - Time-Based Observations and Correlations, 110
- Conclusions, 110
- References, 111

*Chapter 5: Stanley D. Wilson and P. Erik Mikkelsen*

## FIELD INSTRUMENTATION

- Instrumentation Planning, 112
  - Types of Measurements Required, 113
  - Selection of Instrument Types, 113
- Surface Surveying, 113
  - Conventional Surveying, 113
  - Other Types of Surface Surveying, 117
  - Crack Gauges, 118
  - Tiltmeters, 118
- Inclinometers, 118
  - Inclinometer Sensors, 121
  - Casing Installation, 122
  - In-Place Inclinometers, 124
- Extensometers and Strain Meters, 124
- Pore-Pressure and Groundwater Measurements, 125
  - Observation Well, 125
  - Piezometers, 125
  - Piezometer Sealing, 127
- Systems for Monitoring Rock Noise, 128
  - Sensors, 128
  - Signal-Conditioning Equipment, 128
  - Recording and Data-Acquisition Equipment, 129
- Automatic Warning and Alarm Systems, 129
- Data Acquisition and Evaluation, 129
  - Data-Acquisition Methods, 129
  - Inclinometer Observations, 130
  - Inclinometer Data Reduction, 131
  - Evaluation and Interpretation, 132
- Examples, 133

- Minneapolis Freeway, 133
- Potrero Tunnel Movements, 134
- Seattle Freeway, 134
- Fort Benton Slide, 135
- References, 137

*Chapter 6: Tien H. Wu and Dwight A. Sangrey*

## STRENGTH PROPERTIES AND THEIR MEASUREMENT

- General Principles, 139
  - Mohr-Coulomb Failure Criterion, 139
  - Effective Stress Versus Total Stress Analysis, 139
  - Common States of Stress and Stress Change, 140
  - Stress-Strain Characteristics, 140
  - Effect of Rate of Loading, 140
- Laboratory Measurement of Shear Strength, 141
  - Simple Tests, 141
  - Triaxial Test, 141
  - Plane-Strain Test, 143
  - Direct Shear Test, 143
  - Simple Shear Test, 143
- Shear Strength Properties of Some Common Soils, 144
  - Cohesionless Soils, 144
  - Soft Saturated Clays and Clayey Silts, 144
  - Heavily Overconsolidated Clays, 145
  - Sensitive Soils, 148
  - Partially Saturated Soils, 149
  - Residual Soil and Colluvium, 149
  - Rocks, 150
- Soil Behavior Under Repeated Loads, 151
  - Repeated Load Tests, 151
  - Stress-Strain Characteristics, 151
  - Failure Under Repeated Loading, 152
- References, 152

*Chapter 7: N. R. Morgenstern and Dwight A. Sangrey*

## METHODS OF STABILITY ANALYSIS

- Roles of Limit Equilibrium and Deformation Analyses, 155
- Limit Equilibrium Analysis, 156
  - Total and Effective Stress Analyses, 157
  - Total Stress Analysis of Soil Slopes ( $\phi = 0$ ), 157
  - Effective Stress Analysis of Soil Slopes, 160
  - Pore-Pressure Distribution, 165
  - Analysis of Rock Slopes, 165
- Deformation Analysis, 168
- References, 169

*Chapter 8: David S. Gedney and William G. Weber, Jr.*

## DESIGN AND CONSTRUCTION OF SOIL SLOPES

- Philosophy of Design, 172
- Safety Factor, 172
- Design Procedures, 173
  - Avoid Problem, 173
  - Reduce Driving Forces, 175
  - Increase Resisting Forces, 183
- Toe Erosion, 190
- References, 190

## ENGINEERING OF ROCK SLOPES

- Significant Factors in Design of Rock Slopes, 193
  - Structural Discontinuities, 193
  - Groundwater, 194
  - Lithology, Weathering, and Alteration, 194
  - Climatic Conditions, 195
  - Slope Geometry in Plan and Section, 196
  - Time Factor and Progressive Failure, 196
  - Residual and Induced Stress, 196
  - Existing Natural and Excavated Slopes, 197
  - Dynamic Forces, 197
- Fundamental Procedures in Analysis of Rock Slopes, 197
  - Determination of Structural and Other Relevant Geologic Characteristics, 197

- Determination of Structural Domains and Design Sectors, 198
- Development of a Rock Mass Model Depicting Geologic Structure, 198
- Determination of Kinematically Possible Failure Modes and Performance of Slope-Stability Analysis, 199
- Slope Design and Remedial Measures, 201
  - Planning and Related Procedures, 201
  - Methods of Stabilization, 205
  - Methods of Protection, 218
  - Methods of Warning, 223
- References, 225

## INDEX, 229